1. PROJECT OVERVIEW

1.1 Scientific Frontiers Available for Exploration by eRHIC

The tremendous growth of knowledge about the fundamental structure of matter during the 20th century culminated in the 1970s with the emergence of the Standard Model. The Standard Model is an elegant theoretical framework based on experiment, which describes the structure of all matter in terms of point-like particles interacting by the exchange of gauge bosons. The point particles are termed leptons (electrons, neutrinos, etc.) or quarks (up, down, strange, etc.) and three types of gauge bosons; photons, weak bosons (W, Z), and gluons. Leptons can only exchange photons or weak bosons while the quarks may also exchange gluons. In addition, gluons, unlike photons, can interact with each other. The force governing the interaction of quarks and gluons is called the strong force. It is responsible for the structure of nucleons and their composite structures, atomic nuclei, as well as neutron stars.

Nucleons were born in the first minutes after the "Big Bang", and their subsequent synthesis into nuclei goes on in the ever-continuing process of nuclear synthesis in stars. Nuclear matter makes up most of the mass of the visible universe. It is the stuff that makes up our planet and its inhabitants. Nuclear matter was once remote and difficult for humans to access, but in the latter half of the 20th century, understanding nuclear matter and its interactions became central to research in nuclear physics and important to research in energy, astrophysics, and defense.

An essential goal of present day research is to investigate and understand the strong interactions between quarks and gluons that underpin the structure and interactions of nucleons and nuclei. The proposed electron-ion collider at BNL (eRHIC) is the essential next step needed to study the fundamental states of matter. We believe that it must be constructed by the end of the present decade to continue progress in this vital field of science.

1.1.1 Background and Scientific Questions

It is widely accepted that QCD is the exact theory of the strong interaction. QCD has a unique standing among all components of the Standard Model. It is the only theory that is not singular at short distances. The phenomenon of confinement ensures that QCD is well-behaved at large distances. Thus, QCD appears to be the only self-consistent nontrivial quantum field theory.

One of the greatest achievements of particle physics over the last 30 years was a quantitative verification of QCD in very hard collisions; those that occur over short distances at least 10 times smaller than the size of the proton. In hard collisions, the confined quarks and gluons act as if they are free particles exhibiting many properties that can be predicted by perturbative QCD (pQCD). However, when the interaction distance between partons (constituents of the nucleon) becomes comparable to or larger than the typical size of hadrons (pions and other heavier constituents that take part in the strong interaction), the partons are no longer free. They are confined by the strong force that does not allow observation of any free "colored" object. In this regime where most hadronic matter exists, many of the symmetries of the underlying quark-gluon theory are hidden and simple calculation methods are no longer valid. This is a fascinating many-body problem where very strong forces obscure the relationship with the simple underlying theory. Understanding the relationship between the quark-gluon degrees of freedom and the hadrons that contain them is the most urgent challenge to any future experimental program in the domain of the strong interaction.

The most important difference between the theory of electromagnetic interactions, Quantum Electro-Dynamics (QED), and QCD is that gluons interact with each other while photons do not interact with other photons. This built-in non-linearity (non-Abelian structure) makes QCD calculations and theoretical predictions difficult, except in the high-energy (perturbative) or short space-time limit. The technical difficulties encountered in calculating QCD at the hadronic scale may be overcome by the use of lattice gauge calculations employing specifically designed powerful "tera-flop" computers. Over the next decade we expect that numerical computations of QCD will be extended into the non-perturbative regime. At that time, the properties of nucleons and nuclei will have a quantitative foundation in the fundamental theory. However, even at that time, the properties of hadrons at high energies will be well beyond the reach of the fastest computers. The thrust of this proposal is to provide physicists with an experimental tool that can explore all the partonic manifestations of QCD in nucleons and nuclei as well as explore the space-time structure of confinement.

Experimentally, the quark substructure of the nucleon was first revealed through electron-proton Deep Inelastic Scattering (DIS) experiments that took place at the Stanford Linear Accelerator Center (SLAC) in the early 1970s. These experiments earned a Nobel Prize for Friedman, Kendall, and Taylor. In a DIS collision, the electron transfers a large amount of energy and momentum. This energy and momentum is taken up by one of the quarks present in the proton. The struck quark carries a fraction of the proton's momentum, denoted by x, which is readily determined by the energy and momentum transferred in the collision. By varying the kinematics of the large momentum transfer scattering, on can measure the quark distribution as a function of that momentum.

A great deal has been learned since, at CERN, SLAC, Fermilab and DESY, about the quark and gluon structure of hadronic matter through measurements of quark and gluon distributions. In fact, the modifications of these distributions brought about by nucleons bound in nuclear medium were measured in groundbreaking experiments at SLAC, CERN and Fermilab. However, some of the crucial questions about the structure of hadronic matter remain open:

- What is the *structure* of hadrons in terms of their quark and gluon constituents?
- How do quarks and gluons *evolve* into hadrons through the dynamics of confinement?
- How do the quarks and gluons manifest themselves in the properties of atomic nuclei?

The term *"structure"* refers both to momentum distribution and to the spin carried by the various constituents. The answers to these questions are central to the ultimate characterization of the microscopic structure of strongly interacting matter.

However, a complete understanding of QCD and its full implications goes beyond these questions. The many-body aspects of QCD remain largely unexplored, and may contain a variety of surprises that can only be revealed by new measurements in domains that until now have been inaccessible. Finally, while today precision experiments test QED to its limits, similar explorations of QCD are incomplete because of the limitations in presently available experimental capabilities. Thus, there are a second group of questions:

- Does partonic matter saturate in a universal high-density state?
- Are there any long range correlations between produced partons?
- Can studies of the dependence of the parton densities on the nuclear density help constrain the properties of nuclear matter in the center of a neutron star?
- To what degree can QCD be demonstrated as an exact theory of the strong interaction?

1.1.2 The Electron Ion Collider at BNL: eRHIC

The electron-ion collider at BNL (eRHIC) is proposed as a means to obtain experimental answers to all of these questions. The design requirements are shaped by three decades of experimental work carried out with stationary or fixed targets at high-energy physics facilities such as SLAC, CERN, DESY, and Fermilab. In addition, a significant amount of effort was expended at DESY to investigate future polarized electron-proton (e-p) and unpolarized electron-ion (e-A) options. The inherent limitations of these facilities points to the need for a facility with the following characteristics:

- Collider geometry where electron beams collide with beams of protons or light and heavy nuclei,
- Wide range of collision energies (from E_{cm}/nucleon = 30 GeV to 100 GeV),
- High luminosity $L = 10^{33}$ cm^{-2} s^{-1} per nucleon,
- Polarization of electron and proton spins, and
- Preferably, two interaction regions with dedicated, nearly hermetic, detectors.

Collider geometry offers two major advantages over fixed target electron-proton/ion (e - p/A) studies. First, the collider delivers vastly increased energy to the collision, providing a greater range for investigating partons with small momentum fractions (x) and their behavior over a wide range of momentum transfers (Q^2).

In DIS the accessible values of x are limited by the available collision center-of-mass energy. For example, collisions between a 10-GeV electron beam and nuclear beams of 100 GeV/nucleon provide access to values of x as small as $3x10^{-4}$. In a fixed target configuration a 2.1TeV electron beam would be required to produce the same collision energy. Figure 1.1 a-b shows the x-Q^2 range possible with the eRHIC and compares that range to the presently explored kinematic region. The beam energies assumed for the eRHIC are:

- 100 GeV/nucleon for nuclear beams,
- 50-250 GeV for polarized/unpolarized proton beams, and
- 5-10 GeV/c for polarized electron/positron beam.

The only electron-proton collider in existence is HERA, which is limited to unpolarized electron-proton collisions. Thus, in the case of electron-nucleus and polarized electron-polarized nucleon collisions the eRHIC is entering entirely new territory.

Secondly, the collider geometry is far superior to fixed-target experiments since it allows examination of final states of the target. If one wishes to examine the final state fragments from the struck nucleon or nucleus in fixed-target geometry, it is necessary to use a thin target so that the fragments can escape the target and be detected. The thin target makes acquisition of adequate statistics a serious problem. This is easily overcome in a high-luminosity collider, where high luminosity provides an adequate collision rate, and the boost acquired by target fragments in the collider mode makes them readily available for detection when separated from the beam.
High luminosities of the order of $L=10^{33}$ cm^{-2} s^{-1} for electron-nucleon scattering, are a necessary and crucial characteristic of the eRHIC. It corresponds to observing 86 pb^{-1} per day. Previous studies established that significant results are attained at 200 $(pb)^{-1}$, therefore the statistical precision required for significant physics is easily within the reach of the eRHIC. This luminosity can be achieved with either of two accelerator scenarios: a ring-ring configuration, and a ring-electron linac configuration. Each has advantages. Achieving the proposed luminosities requires electron cooling of the ion beams (except at the highest proton energies) and intense electron beams of about 500 mA. While challenging, the intense electron beams are already available at the presently operating B-factories (SLAC and KEK B). The electron linacs (one for cooling the ion beam and another providing high-

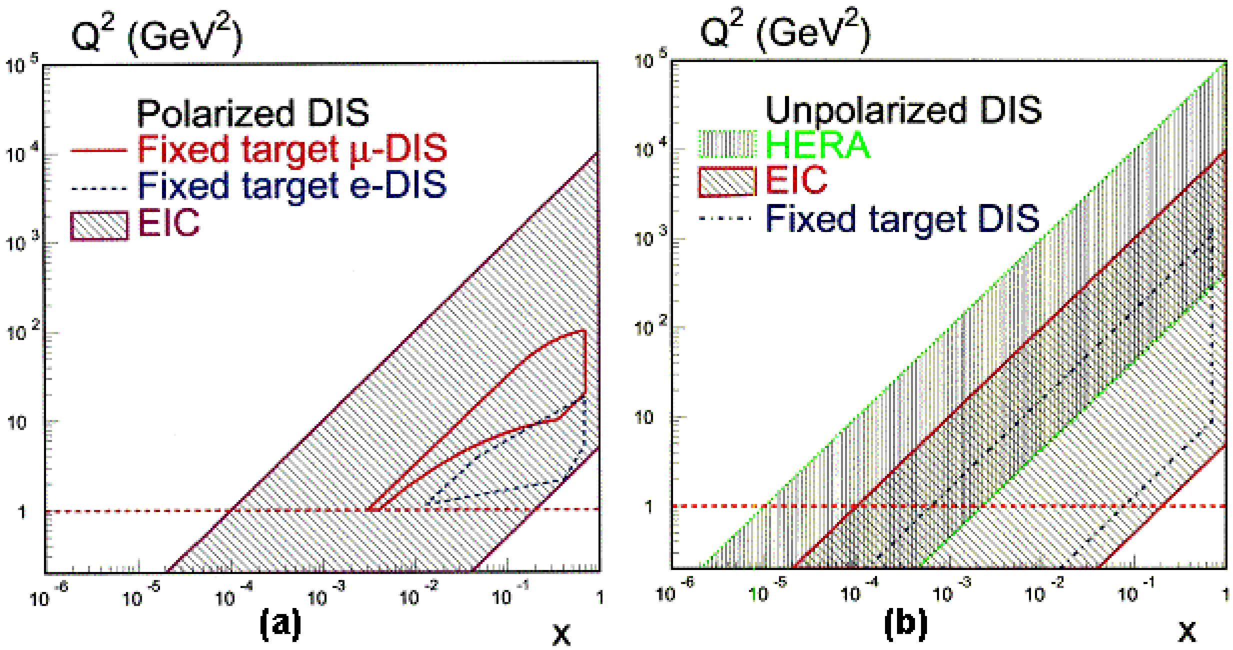

Figure 1.1: x-Q^2 Range of the Proposed Electron Ion Collider

The x-Q^2 coverage of the eRHIC is compared with previously measured ranges. Figure (a) is for polarized lepton - nucleon DIS while (b) is for unpolarized lepton-nucleon and lepton - nucleus DIS, where leptons can be electrons or muons. Note that the HERA coverage in (b) is for e – p scattering only while the fixed target and the eRHIC regions also include DIS off nuclear targets.

energy electrons in the collider) require full-energy recovery following the model of the full-energy recovery 50 MeV linac-based free electron laser at Thomas Jefferson Laboratory. Figure 1.2 shows the unique parameters of the eRHIC in the context of existing and planned lepton scattering facilities worldwide. The eRHIC will have higher energies than any existing fixed target machine and a higher luminosity than any existing collider.

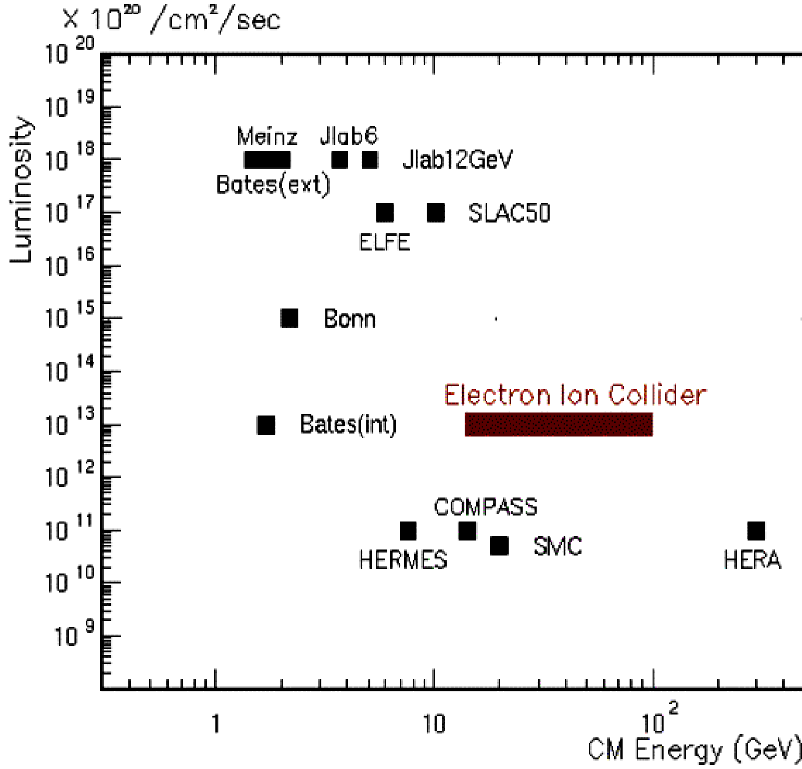

Figure 1.2 The Center-of-Mass Energy vs. Luminosity of eRHIC Relative to Other Facilities
The center-of-mass vs. energy of various existing facilities compared to that proposed for the eRHIC

1.1.3 Highlights of Scientific Frontiers Open to the eRHIC

Quark and Gluon Distributions in the Nucleon

The eRHIC offers a unique capability for measuring "flavor tagged" structure functions by providing access to a wide range of final states arising from the fragmentation of the virtual photon. The collider geometry makes measurement of semi-inclusive reactions very efficient so that quark and gluon distributions in nucleons, nuclei, and possibly even mesons can be mapped in a flavor-tagged mode. This will provide a decomposition of the parton densities, over a large kinematic range, into the contributions from different parton types: up, down and strange quarks as well as gluons. For example, with clean kaon identification both the momentum and spin distributions of strange quarks can be determined with high precision down to $x \sim 10^{-3}$. The ability to tag the hadronic final state will allow measurements of the neutron structure function at large x, so that a reliable and precise determination of the ratio of the quark distribution in neutrons and protons can be made in a regime where several competing theoretical predictions exist.

Spin Structure of the Nucleon

Fixed target polarized DIS experiments yielded the surprising information that the quark spins account for only ~30% of the total spin of the nucleon. Recent results, with large uncertainty, indicate that gluons may play a significant role in constituting the nucleon's spin. While experiments with polarized protons at the Relativistic Heavy Ion Collider (RHIC) will provide significant information for unraveling the role of gluonic spin, energetic collisions using polarized electrons and protons will provide important complementary, and in some instances, essential new information using well established experimental methods and theoretical techniques presently used by the DIS community at HERA. The eRHIC, running at its highest energy, will provide crucial data at lower x than has been possible in any previous experiment. The use of tagging in polarized nuclei will allow measurement of the spin structure of the neutron at large x with better precision. At small x it will provide a separation between the polarization effects in the vacuum and nonvacuum channels. Determination of spin structure functions in this yet unmeasured low x region will bring a unique perspective to our understanding of pQCD. Direct measurement of the polarization of quarks in a broad range of x are needed to determine the polarization of quarks and antiquarks in the sea, currently a matter of controversy within sophisticated and successful models of the nucleon.

Correlations between Partons

A complete characterization of the partonic substructure of the nucleon must go beyond a picture of collinear non-interacting partons. It must include a description of the correlations between the partons densities over impact parameters, and a comparison of the parton wave functions of different baryons. Progress in this direction can be realized by measuring hard exclusive processes where, in the final state, a photon, a meson or several mesons are produced along the virtual photon direction, and a baryon is produced in the nucleon fragmentation region. These processes are expressed, as a result of the new QCD factorization theorems, through a new class of parton distributions termed *Generalized Parton Distributions* (GPD). The collider kinematics are optimal for detecting these processes. The presence of polarization provides additional exciting opportunities, for example, comparisons of the spin structure of hyperons and nucleons. If successful, such a program would greatly expand our knowledge about the role of non-perturbative QCD in hadronic structure.

The Role of Quarks and Gluons in Nuclei

Most hadronic matter exists in the form of nuclei. The ability of the eRHIC to collide electrons with light and heavy nuclei opens horizons fundamental to nuclear physics. For example, the role of quarks and gluons in nuclei may be investigated by comparing the changes in parton distributions per nucleon as a function of the number of nucleons. Seminal DIS experiments off nuclei showed that a) the distribution of quarks is altered by the nuclear medium from that observed in nucleons, b) led to the discovery of the lack of enhancement of sea quarks in the nuclei that was expected based on models of the meson picture of nuclear forces, and c) provided tantalizing indications of significant modifications of the gluon distributions at moderate x. Studies of parton modifications at $x \sim 0.1$ will be most sensitive to the underlying quark-gluon structure of the internucleon interactions that are usually described within effective low energy mesonic theories. It is particularly important to establish the quark distributions at small values of x where the presence of the other nucleons in the nucleus will alter (“shadow”) the partonic distributions. A nuclear enhancement of valence quarks, sea quarks, or gluons would indicate the relative importance of meson, quark, and gluon exchange at various distance scales.

Hadronization in Nucleons and Nuclei

How do the colored quarks and gluons knocked out of nucleons in DIS evolve into the colorless hadrons that must eventually appear? This process is one of the clearest manifestations of confinement: the asymptotic physical states must be color-neutral. Hadronization is a complex process that involves both the structure of hadronic matter and the long range nonperturbative dynamics of confinement. A fundamental question related to hadronization is how and to what extent the spin of the quark is transferred to its hadronic daughters. The ability to "tag flavor" and a facility that creates readily detectable jets are crucial for these experiments. The eRHIC makes it possible to strike quarks and observe the complete array of decay products from the nucleon or nucleus. The fact that nuclei also may be used is essential to this study. The ability to place varying amounts of nuclear matter in proximity to the system produced forward along the photon direction and the recoiling quark system, allows one to perturb in a controlled way the early stages of its space-time evolution, and to measure the energy imparted to the nuclear matter by the emerging parton.

Partonic Matter Under Extreme Conditions

Very high energy DIS on nuclear targets with electromagnetic probes offers new opportunities for studying partonic matter under extreme conditions. Particularly intriguing is the regime of very low x ($x < 10^{-3}$) where gluons dominate. Measurements of the proton structure function showed that the gluon distribution grows rapidly at small x for Q^2 greater than a few GeV^2. When the density of gluons becomes large, they may saturate and give rise to a new form of partonic matter: a **color glass condensate**. It is a colored glass because the properties of the color-saturated gluons are analogous to that of a spin glass system in condensed matter physics. It is a condensate because the gluons have a large occupation number and are peaked in momentum about a typical scale of the saturation momentum Q_s.

This state of strongly interacting matter would be universal in that it is insensitive to the hadronic matter in which it resides. The gluonic density/cm^2 is enhanced in nuclei relative to that in individual nucleons by a factor $A^{1/3}$. Therefore, high parton density effects will appear at much lower energies in nuclei than in protons. The eRHIC, with its nuclear beams and e - A center-of-mass energies of at least 60 GeV, and ability to study inclusive and semi-inclusive observables, will probe this novel regime of Quantum Chromo Dynamics.

1.2 General accelerator concept and parameters

1.2.1 Project Goals

The physics program outlined in the previous section sets requirements and goals for the electron-ion collider to be successful and efficient tool for intended physics research . These goals include wanted luminosity level, range of beam collision energies and using polarized beams. On the other side, to be realistic, the goals should be based on the present understanding of the existing RHIC machine and limitations which arise from the machine itself. Possible realistic machine upgrades should be considered to overcome existing limitations and to achieve advanced machine parameters, but those upgrades should not be extensive and costly.

The intent to minimize required upgrades in the existing RHIC rings affects the choice of parameters and the set of goals. Another guideline, which was defined for the design described in this report and which affects the choice of the beam parameters and the value of achievable luminosity, is capability of the collider to operate in the same time with ion-ion and electron-ion collisions. In the main design line collisions in two ion-ion interaction regions, at the 6 and 8 o'clock, have to be allowed in parallel with electron-ion collisions.

Taking into account all mentioned above, following goals were defined for the accelerator design:

- The machine should be able to provide the beams in following energy ranges:
    - The electron accelerator:
        - 5-10 GeV polarized electrons;
        - 10 GeV polarized positrons;
    - The ion accelerator:
        - 50-250 GeV polarized protons;
        - 100 GeV/u Gold ions
- Luminosities:
    - in 10^{32}-10^{33} cm^{-2}s^{-1} range for e-p collisions
    - in 10^{30}-10^{31} cm-2s-1 range for e-Au collisions
- 70% polarization degree for both lepton and proton beams
- Longitudinal polarization in the collision point for both lepton and proton beams

Additional goal for the design was to look at possibility of accelerating polarized ions, especially polarized ^{3}He ions.

1.2.2 General Layout

The present RHIC machine uses superconducting dipole and quadrupole magnets to keep ion beams circulating in two rings on 3834m circumference. The beam energy range covers 10.8-100 Gev/u for Au ions and 25-250 GeV for protons. There are in total 6 intersection points where two ion rings, Blue and Yellow, cross each other. Four of these intersection points are presently used by physics experiments and have experimental detectors installed.

General layout of a suggested eRHIC collider is shown in Figure 1.3. The main project line is to construct an electron storage ring which will intersect the RHIC Blue ion ring in one of existing interaction regions, not used by any of ion-ion collision experiments. The new detector, developed and optimized for electron-ion collision physics studies, shall be constructed in that intersection point.

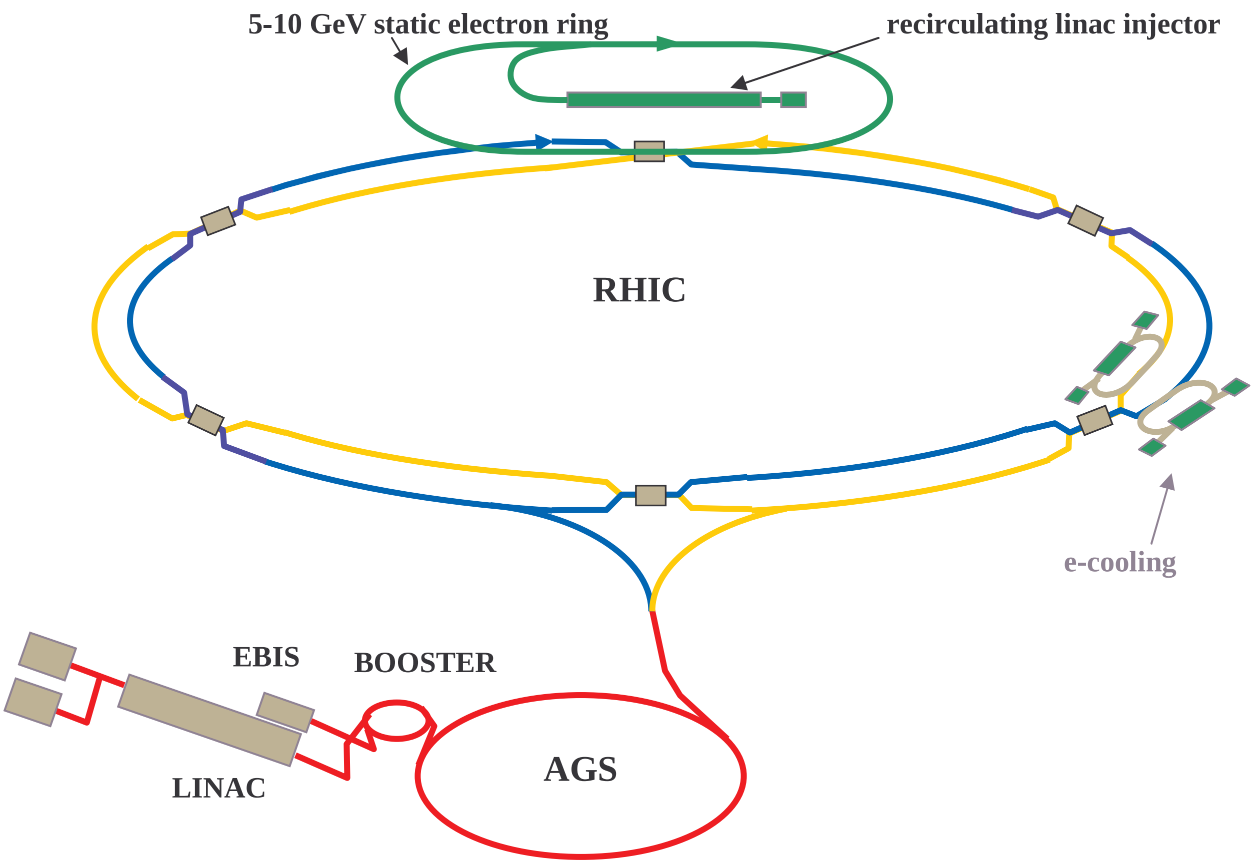

Figure 1.3: Design layout of the eRHIC collider.

Electron beam in this design is produced by polarized electron source and accelerated in a linac injector to the energies of 5 to 10 GeV. In order to reduce the injector size and , therefore, the injector cost, the injector design includes recirculation arcs, so that the electron beam passes same accelerating linac sections multiple times. Two possible linac designs, superconducting and normal conducting, have been considered. The beam is accelerated by the linac to the required collision energy and injected into the storage ring.

The electron storage ring should be capable of storage the electron beam at the energy range of 5 to 10 GeV with appropriate beam emittance values. It does not provide any additional acceleration for the beam. The electron ring should minimize depolarization effects in order to keep the electron beam polarization at the high level for the time of a store which is on the scale of several hours.

The injector system also includes the conversion system for positron production. After production the positrons are accelerated to 10 GeV energy and injected into the storage ring the same way as the electrons. Obviously the field polarities of all ring magnets should be switched to opposite at the positron operation mode. Unlike electrons the positrons are produced unpolarized and have to be polarized in the ring. Therefore the design of the ring should allow for sufficiently small polarization time. The current ring design provide polarization time about 20min at 10 GeV. But with polarization time increasing sharply as beam energy goes down the use of polarized positron beam in the present design are limited to 10 GeV energy.

The detailed description of the electron injector system, electron ring and all issues relevant for their design is presented in Chapter 2. It is important to note that the electron accelerator design described there is based on present day level of accelerator technology and does not require extensive R&D studies. This, in fact, has been one of requirements for the main design line for this ZDR.
In order to organize electron-ion collisions one of RHIC interaction regions has to be reconstructed. Figure 1.3 shows the design with electron accelerator located at 12 o'clock region . As discussed in section 2.2 of this report another possible location for the electron accelerator and for electron-ion collisions might be at 4 o'clock region. For collisions with electrons the ion beam in the RHIC Blue ring will be used, since the Blue ring can operate alone, even with another ion ring, Yellow, being down. The interaction region design which provides fast beam separation for electron and Blue ring ion bunches as well as strong focusing at the collision point is described in Chapter 4. In the design, another ion ring, Yellow, makes 3m vertical excursion around the collision region, avoiding collisions both with electrons and Blue ion beam. Interaction region includes spin rotators, in both electron and Blue ion rings, with a goal to produce longitudinally polarized beams of electrons and protons at the collision point.
Electron cooling system showed in Figure 1.1 is one of upgrades required for ion rings. The cooling would be necessary to reach luminosity goals for electron collisions with gold ions and low (below 150 GeV) energy protons. The electron cooling is an essential part of RHIC upgrade for higher luminosity in ion-ion collisions, RHICII, which would be realized on a time scale before the eRHIC.
Also the present design considers using a total ion beam current higher than the current being used at the present RHIC operation. 360 bunch mode operation is evaluated in this report for the ion beam. The electron cooling, the beam intensity increase as well as proton and ion beam polarization issues, are described in Chapter 3 of the report.
Another proposed electron accelerator design is described in Appendix A. That design considers the use of high current polarized electron beam accelerated to collision energies by a superconducting energy recovery linac. In that case the electron beam is delivered to an interaction point directly from the linac. The design results in a higher luminosity value but requires intense R&D studies to develop and test technologies for high current polarized electron source and high beam power energy recovery.

1.2.3 Design Luminosities

The eRHIC design has been created and optimized to achieve luminosity goals listed in previous section The luminosity is limited mainly by maximum achievable beam-beam parameters and by interaction region magnet aperture limitations. Following those limitations it is most appropriate and convenient to use a luminosity expression through beam-beam parameters (ξ_e,ξ_i) and rms angular spread in the interaction point (σ'_{xi}, σ'_{ye}):

$$L = f_c \frac{\pi\gamma_i\gamma_e}{r_i r_e}\xi_{xi}\xi_{ye}\sigma'_{xi}\sigma'_{ye}\frac{(1+K)^2}{K} \qquad (1.1)$$

The f_c = 28.15 MHz is a collision frequency, assuming 360 bunches in the ion and 120 bunches in the electron ring. The parameter $K=\sigma_y/\sigma_x$ presents the ratio of beam sizes in the interaction point. One of basic conditions which defines the choice of beam parameters is a requirement on equal beam sizes of ion and electron beams at the interaction point: $\sigma_{xe}=\sigma_{xi}$ and $\sigma_{ye}=\sigma_{yi}$. The requirement is based on operational experience of HERA collider and on the reasonable intention to minimize the amount of one beam passing through strongly nonlinear field in outside area of the counter rotating beam.

According to the expression (1.1) the luminosity reaches a limiting value at maximum values of beam-beam parameters, or at beam-beam parameter limits. For protons (an ions) the total beam-beam parameter limit was assumed at 0.02 value, following the experience and observation from other proton machines as well as initial experience from the RHIC operation. With three beam-beam interaction points, two for proton-proton and one for electron-proton collisions, the beam-beam parameter per interaction point should not exceed 0.007.

For the electron (or positron) beam a limiting value of beam-beam parameter has been put at 0.08 for 10GeV beam energy, following the results of beam-beam simulation (see Chapter 2), as well as the experience from electron machines of similar energy range. Since the beam-beam limit decreases proportionally with the beam energy, the limiting value for 5 GeV is reduced to 0.04.

The available magnet apertures in the interaction region also put a limit on the achievable luminosity. The work on the interaction region design revealed considerable difficulties to provide an acceptable design for collisions of round beams. The IR design, described in Chapter 4, has been worked out to provide low beta focusing and efficient separation of elliptical beams, with beam size ratio K=1/2. The main aperture limitation comes from the septum magnet, which leads to the limiting values of $\sigma'_{xp} = 93\mu\mathrm{rad}$.

Another limitation, which should be taken into account is a minimum acceptable value of beta-function at the interaction point. With the proton rms bunch length of 20cm, decreasing β^* well below this number results in a luminosity degradation due to the hour-glass effect. The limiting value β^*=19cm has been used for the design, which results in hour-glass luminosity reduction only by about 12%. 20cm bunch length for Au ions would be achieved with electron cooling.

Table 1.1 and Table 1.2 below show design luminosities and beam parameters. A positron beam is supposed to be of similar to electron beam intensity (see Chapter 2), hence the luminosities for collisions involving positron beam are equivalent to electron-ion collision luminosities.

To achieve the high luminosity with low energy setup in Table 1.1 the electron cooling has to be used to shrink normalized transverse emittance of lower energy proton beam to 5π mm.mrad. Also, in that case the proton beam should have collisions only with electron beam. Proton-proton collisions in other two interaction points have to be avoided to allow for higher proton beam-beam parameter.

The maximum luminosity achieved at the present design is 4.4×10^{32} $cm^{-2}s^{-1}$ in high energy collision mode (10GeV electron on 250GeV protons). Section 2.4.2 discusses a possible path to luminosities (see Table 2.4.2-2) as high as 10^{33} , with studies planned to explore the feasibility of higher electron beam intensity operation.

To achieve and maintain Au normalized transverse beam emittances shown in Table 1.2 the electron cooling will be used. For the lower energy setup of electron-gold collisions, the intensity of the gold beam is considerably reduced because of reduced value of beam-beam parameter limit for the electron beam.

Table 1.3 shows parameters for possible electron-$^3He^{+2}$ operation mode with He beam intensity limited by electron beam-beam limit.

Table 1.1. Luminosities and main beam parameters for electron(positron)-proton collisions.

	High energy setup		Low energy setup	
	p	e	p	e
Energy, GeV	250	10	50	5
Bunch intensity, 10^{11}	1	1	1	1
Ion normalized emittance, π mm $\cdot$ mrad , x/y	15/15		5/5	
rms emittance, nm, x/y	9.5/9.5	53/9.5	16.1/16.1	85/38
β*, cm, x/y	108/27	19/27	186/46	35/20
Beam-beam parameters, x/y	0.0065/0.003	0.03/0.08	0.019/0.0095	0.036/0.04
$\kappa=\varepsilon_y/\varepsilon_x$	1	0.18	1	0.45
Luminosity, 1.e32 $cm^{-2}s^{-1}$	4.4		1.5	

Table 1.2. Luminosities and main beam parameters for electron(positron)-Au collisions.

	High energy setup		Low energy setup	
	Au	e	Au	e
Energy, GeV/u	100	10	100	5
Bunch intensity, 10^{11}	0.01	1	0.0045	1
Ion normalized emittance, π mm $\cdot$ mrad , x/y	6/6		6/6	
rms emittance, nm, x/y	9.5/9.5	54/7.5	9.5/9.5	54/13.5
β*, cm, x/y	108/27	19/34	108/27	19/19
Beam-beam parameters, x/y	0.0065/0.003	0.0224/0.08	0.0065/0.003	0.02/0.04
$\kappa=\varepsilon_y/\varepsilon_x$	1	0.14	1	0.25
Luminosity, 1.e30 $cm^{-2}s^{-1}$	4.4		2.0	

Table 1.3. . Luminosities and main beam parameters for electron(positron)-$^3He^{+2}$ collisions.

	High energy setup		Low energy setup	
	He	e	He	e
Energy, GeV/u	167	10	167	5
Bunch intensity, 10^{11}	0.7	1	0.18	1
Ion normalized emittance, π mm $\cdot$ mrad , x/y	10/10		10/10	
rms emittance, nm, x/y	9.4/9.4	48/13	9.4/9.4	48/13
β*, cm, x/y	108/27	21/19	108/27	21/19
Beam-beam parameters, x/y	0.0065/0.003	0.045/0.08	0.0065/0.003	0.02/0.04
$\kappa=\varepsilon_y/\varepsilon_x$	1	0.28	1	0.28
Luminosity, 1.e32 $cm^{-2}s^{-1}$	3.1		0.8	